7.3 Fields and Potential Energy

SECTION EXPECTATIONS

- Define and describe the concepts and units related to electric and gravitational fields.
- Apply the concept of electric potential energy and compare the characteristics of electric potential energy with those of gravitational potential energy.

KEY TERMS

- electric potential difference
- equipotential surface

As a thundercloud billows, rising ice crystals collide with falling hailstones. The hail strips electrons from the rising ice and the top of the cloud becomes predominantly positive, while the bottom is mostly negative. Negative charges in the lower cloud repel negative charges on the ground, inducing a positive region, or "shadow," on Earth below. Electric fields build and a spark ignites a cloud-to-ground lightning flash through a potential difference of hundreds of millions of volts.

The lightning bolt featured in Figure 7.14 dramatically demonstrates that when a charge is placed in an electric field, it *will* move. The potential to move implies the existence of stored energy. In this chapter, you will focus on the energy stored in the gravitational and electric fields.

Figure 7.14 Tremendous amounts of electric energy are "stored" in the electric fields created by the separation of charge between thunderclouds and the ground. This energy is often released in the "explosion" of a lightning bolt.

Potential Energy

In Chapter 6, Energy and Motion in Space, you derived an equation for the gravitational potential energy of one mass due to the presence of a central mass. You started the derivation by determining the amount of work that you would have to do on the first mass to move it from a distance r_1 to a distance r_2 from a central mass. Then you learned that physicists have agreed on a reference

position that is assigned a value of zero gravitational potential energy. That distance is infinitely far from the central mass. In this application, an infinite distance means so far away that the magnitude of the force of gravity is negligible.

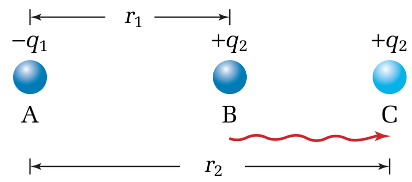

Figure 7.15 By doing work on charge q_2, you give it potential energy.

Physicists take the same approach in developing the concept of electric potential energy of a charge q_1 in the vicinity of another charge q_2 as shown in Figure 7.15. The change in electric potential energy of charge q_1 due to the presence of q_2, in moving q_1 from r_1 to r_2, is the work that you would have to do on the charge in moving it. In Figure 7.16, note the similarities in the equations for the force of gravity and the Coulomb force as well as the curves for force versus position.

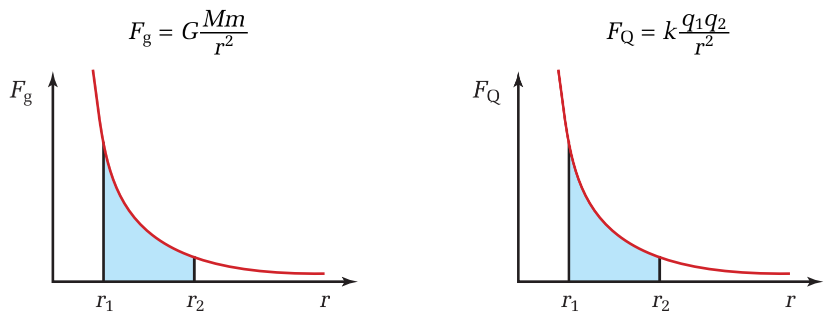

Figure 7.16 The Coulomb force and the force of gravity both follow inverse square relationships, so the curves of force versus position have exactly the same form.

Since the two equations and the two curves have identical mathematical forms, the result of the derivation of the change in the electric potential energy in moving a charge will be mathematically identical to the form of the change in the gravitational potential energy in moving a mass from position r_1 to position r_2.

$$\Delta E_g = \frac{GMm}{r_1} - \frac{GMm}{r_2} \qquad \Delta E_Q = \frac{kq_1q_2}{r_1} - \frac{kq_1q_2}{r_2}$$

The choice of a reference position for electric potential energy is the same as that for gravitational potential energy — an infinite distance — so far apart that the force between the two charges is negligible. Therefore, the equations for potential energy have the same mathematical form, with one small difference: There is no negative sign in the equation for the electric potential energy.

$$E_g = -\frac{GMm}{r} \qquad E_Q = \frac{kq_1q_2}{r}$$

The negative sign is absent from the equation for electric potential energy, because the energy might be negative or positive, depending on the sign of the charges. If the charges have opposite signs, the Coulomb force between them is attractive. Consequently, if one charge moves from infinity to a distance r from the second charge, it does work and therefore has less potential energy. Less than zero is negative. If the charges have the same sign, you must do work on one charge to move it from infinity to a distance r from the second charge, and therefore it has positive potential energy. If you include the sign of the charges when using the equation for electric potential energy, the final sign will tell you whether the potential is positive or negative.

- Two positive charges $E_Q = \frac{k(q_1)(q_2)}{r}$ $E_Q > 0$ Both q_1 and q_2 are positive, so the charges have positive potential energy when they are a distance r apart.
- Two negative charges $E_Q = \frac{k(q_1)(q_2)}{r}$ $E_Q > 0$ Both q_1 and q_2 are negative, so the charges have positive potential energy when they are a distance r apart.
- A positive and a negative charge. $E_Q = \frac{k(q_1)(q_2)}{r}$ $E_Q < 0$ The product q_1q_2 is negative, so the charges have negative potential energy when they are a distance r apart.

A second difference between electric potential energy and gravitational potential energy is that the two interacting charges might be similar in magnitude. Therefore, either charge could be considered the stationary or central charge, or the "movable" charge. You could therefore consider the two charges to be a system, and refer to the electric potential energy of the system that results from the proximity of the two charges.

SAMPLE PROBLEM

Electric Potential Energy

What is the electric potential energy stored between charges of +8.0 μC and +5.0 μC that are separated by 20.0 cm?

Conceptualize the Problem

- Two *charges* are close together and therefore they exert a *force* on each other.

- *Work* must be done on or to the charges in order to bring them close to each other.
- Since work was done on or by a charge, it has *electric potential energy*.

Identify the Goal

The electric potential energy, E_Q, stored between the charges

Identify the Variables and Constants

Known	Implied	Unknown
$q_1 = 8.0 \times 10^{-6}$ C $q_2 = 5.0 \times 10^{-6}$ C $r = 0.200$ m	$k = 9.0 \times 10^{9} \dfrac{\text{N} \cdot \text{m}^2}{\text{C}^2}$	E_Q

Develop a Strategy

Write the equation for electric potential energy between two charges.

$$E_Q = k\frac{q_1 q_2}{r}$$

Substitute numerical values and solve.

$$E_Q = \frac{\left(9.0 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)(+8.0 \times 10^{-6}\ \text{C})(+5.0 \times 10^{-6}\ \text{C})}{0.200\ \text{m}}$$

$$E_Q = +1.8\ \text{J}$$

The electric potential energy stored in the field between the charges is +1.8 J.

Validate the Solution

Magnitudes seem to be consistent. The units cancel to give J: $\frac{\text{N} \cdot \text{m}^{\cancel{2}}}{\cancel{\text{C}^2}} \cdot \frac{\cancel{\text{C}} \cdot \cancel{\text{C}}}{\cancel{\text{m}}} = \text{N} \cdot \text{m} = \text{J}$. The sign is positive, indicating that the electric potential energy is positive. A positive sign is correct for like charges, because work was done *on* the charges to put them close each other.

PRACTICE PROBLEMS

38. Find the electric potential energy stored between charges of +2.6 μC and −3.2 μC placed 1.60 m apart.

39. Two identical charges of +2.0 μC are placed 10.0 cm apart in a vacuum. If they are released, what will be the final kinetic energy of each charged object (assuming that no other objects or fields interfere)?

40. How far apart must two charges of $+4.2 \times 10^{-4}$ C and -2.7×10^{-4} C be placed in order to have an electric potential energy with a magnitude of 2.0 J?

41. Two charges of equal magnitude, separated by a distance of 82.2 cm, have an electric potential energy of 2.64×10^2 J. What are the signs and magnitudes of the two charges?